Improvement in endoluminal procedures using versatile robot technology

Ramkumar Krishnamoorthy1,2 | Sujeet Kumar2 | Rupal Gupta2

1Iain (deemed to be) University, Bangalore, India, Assistant Professor, Department of Computer Science and Information Technology.
2Vivekananda Global University, Jaipur, India, Assistant Professor, Department of Computer Science and Engineering.
3Teerthanker Mahaveer University, Moradabad, Uttar Pradesh, India, Assistant Professor, College Of Computing Science And Information Technology.

Abstract: Recent Interventional medicine has been radically altered by endoluminal procedures, which can be thought of as minimally invasive surgeries carried out within blood arteries or other hollow structures. The development of multipurpose robot technology has enabled substantial advancements in the performance of various treatments, leading to improvements in precision, maneuverability, and the outcomes for patients. In this study, we investigate the recent developments in the field of endoluminal treatments and the benefits that come along with using adaptable robot technology. Recent technical breakthroughs in robotics and the growing emphasis on less invasive procedures have led to the development of highly adaptable surgical robots. These bendable robots can navigate tight spaces, increasing the accessibility of robotic surgery and perhaps decreasing the number of incisions required. This article describes new flexible surgical robot systems and discusses the most pressing technological challenges in this sector, with a focus on their potential uses in endoluminal surgery. Furthermore, the form and force sensing of flexible robots, as well as the difficulties and recent developments in these areas, are also highlighted as important technological topics. The clinical benefits and technological advancements of new flexible surgical robot systems are also presented, along with their medical applications.

Keywords: surgical robot, endoluminal surgery, hysteresis, continuum robot, robot

1. Introduction

In Endoluminal procedures employ specialized equipment to perform minimally invasive medical procedures into hollow organs or blood vessels of the body. These procedures frequently include small incisions or holes in the body that occur naturally, obviating the need for extensive surgery and resulting in shorter recovery times and lower risks (Morino et al 2021). Numerous disorders affecting the digestive system, cardiovascular system, and respiratory system are regularly diagnosed and treated using endoluminal techniques. To observe and analyze the digestive system, the respiratory system, or other internal organs during an endoscopic procedure, a flexible tube with a light and camera (endoscope) is inserted through the mouth, a skin opening, or a very small incision (Bianchi et al 2019). Endovascular operations can detect and treat problems including peripheral artery disease (PAD), aneurysms, and venous disorders by introducing catheters and wires through tiny incisions into the blood arteries (Race and Horgan 2021). Using endoscopic retrograde cholangiopancreatography, diseases of the pancreas and bile ducts can be identified and treated. An endoscope is inserted into the small intestine, bile, and pancreatic ducts through the mouth. Endoscopic ultrasonography is a method that combines endoscopy with ultrasound technology to view and detect conditions affecting the pancreas, gastrointestinal system, and other organs (Maza and Sharma 2020). Open surgery has a variety of advantages over endoluminal procedures, including less pain, shorter hospital stays, quicker recovery, and a decreased risk of complications. The diagnosis and the patient's specific circumstances will determine the best course of action because endoluminal procedures cannot be employed to address all issues. It is vital to consult a medical specialist when deciding on the best course of treatment for a particular condition (Guo et al 2022). The term "versatile robot technology" refers to the creation and implementation of robotic systems that are capable of carrying out a variety of activities in a variety of fields and applications. By altering or reprogramming their activities or behaviors, these robots are intended to be versatile, adaptive, and capable of carrying out a variety of jobs (Singh et al 2021). In industrial automation repetitive processes like assembly, packing, and material handling, versatile robots are utilized in manufacturing and production lines. Depending on the demands of the company, these robots may be trained to carry out various jobs, increasing productivity and efficiency. Applications in healthcare and medicine: Robots are being utilized more often in healthcare settings for a variety of functions, including surgery, rehabilitation, patient monitoring, and drug distribution. Medical personnel may provide accurate and effective care with the help of adaptable
robots in the industry (Troccaz et al 2019). Automation in logistics and warehouses: Order picking, sorting, and inventory management are all jobs that robots are used for in warehouses and logistics facilities. This industry has adaptable robots that can be configured to handle various product categories and change with the needs of the warehouse (Vrielink et al 2020). Robots are being used in the hotel, retail, and customer service industries. They can assist with product support, communicate with consumers, and give information. They can also clean and maintain inventories. Versatile robots are employed in scientific study and exploration for tasks including deep-sea exploration, environmental monitoring, and space exploration. These robots may be made to adapt to various settings and perform certain activities, delivering useful information and insights (Wang et al 2021). Robot technology’s adaptability is made possible by many elements, including cutting-edge sensors, clever control systems, modular architecture, and the ability to program or reconfigure the robot for various jobs. Robots may be utilized in a variety of applications thanks to their adaptability to diverse conditions and situations (Steiner et al 2019). Article describes new flexible surgical robot systems and discusses the most pressing technological challenges in this sector, with a focus on their potential uses in endoluminal surgery.

2. Related Works

Research (Dagninoet et al 2022) demonstrated that the suggested robotic platform has the potential to enhance the performance of endovascular operations, opening the door to their eventual implementation into clinical practice. They describe the results of an in-depth in-vivo investigation in which their robotic platform was used to perform cannulation and balloon angioplasty on five target arteries in four pig models. Trial results indicated a 100% success rate and post-mortem histological analysis showed that robotic navigation resulted in less vascular stress than hand manipulation. The results of their in-vivo studies showed that their robotic system was safe, feasible, and well-tolerated for use in this research.

Robotic platform that can bend and has a diameter of only 17 mm. A powerful continuum manipulator with the highest resistance to distortion has been devised to counteract form distortion and deflection in payload handling. For master-slave teleoperation, they have devised the kinematic analysis and mapping approach. The suggested manipulator can lift 300 g with a trajectory change of just 7.5 mm. Three distinct types of simulated surgical tasks have confirmed the practicability of the integrated system (Hwang and Kwon 2020).

The length of time it took to do the operation (from making the incision to completing the dissection), the extent to which tissue was removed during the operation, any complications that arose during the surgery, and the difficulty in moving the surgeon’s arms about in the confined area. The present investigation verified the safety and viability of employing the Endo Master System for colorectal Endoscopic sub mucosal dissection (ESD) in a preclinical setting. The system’s capacity to deal with complications including bleeding and perforation was also evaluated (Chiu et al 2021).

To assist medical professional’s in future clinical practice and to inspire and drive new technical innovations, this article aims to present a clear and complete picture of modern robotic gastro scopes and associated technologies. Article (Marlicz et al 2020) provides a comprehensive analysis of the capabilities and performance of these cutting-edge gadgets. Remote tele health endoscopy services are also covered, along with the use of AI technology in robotic gastro scopes.

New surgical modalities with cutting-edge technology, lower prices, and more compact sizes are entering the market as robotic surgery nears a decade of widespread usage in medicine. Focusing on the downsizing of modalities toward the building of micro-scale surgical robots, nicknamed “micro bots,” this chapter seeks to showcase new surgical robotic technologies (Khandalavala al 2020).

After each surgery, a debriefing meeting was held to evaluate the technology used, to improve it, or create new tools to use in the future (Morino et al 2022).

The rapid development of flexible endoscopy has made it an invaluable surgical tool. Revolutionary advances in areas like robots, technology, and Robotics are propelling this change. Several of the most important developments associated with this paradigm shift in gastrointestinal care are presented (Swanström and Pizzicannella 2023).

An emerging subject, robotics in minimally invasive endoscopic procedures has significant challenges from the stringent criteria for downsizing. Inchworm-like devices were described as the first step toward robotic colonoscopy in the 1990s. Since then, colonoscopy with robotic assistance features have hit the market. Future treatments, including those aided by autonomous or robotic agents like robotic capsules, offer more accessibility and flexibility with the help of research prototypes. Improved diagnostic yield may also be expected when such endoscopic technologies are combined with AI-enabled picture analysis and identification algorithms (Ciuti et al 2020).

Article (Osawal et al 2022) developed miniature multi-degree-of-freedom (DOF) endoluminal forceps with solid construction with flexible hinges.

The research (Hwang et al 2020) was to assess the viability of a traction technique using a flexible robotic arm for performing stomach ESD. When performed with a standard flexible endoscope, ESD presents technical difficulties and challenges owing to the absence of enough countertraction to reveal the sub mucosal dissection plane.

3. Key Technical Issues in Flexible Surgical Robots
3.1. Design Manipulator

3.1.1. Types of Flexible Manipulators

Based on these analyses, we widened our definition of a flexible manipulator to encompass not only soft robotics and origami robotics but also continuous backbones, discrete backbones, hybrid backbones, and more. To achieve a continuous backbone, continuous elastic backbones, pre-shaped super elastic tubes, and push-pull actuation are used, as well as shape memory actuators and antagonistic pairs of wires. Responsive manipulators based on a notch flexure hinge are a recent development in the field of flexible manipulator design. The construction of discrete-backboned robots consists of articulated linkages, pivots, and wire-compressed cams; they are operated by push-pull antagonistic actuation of wires; and they are hyper-redundant serial manipulators. To accomplish a decoupled drive, the driving wires are arranged so that they always pass through the center of all joints. Hybrid robots' manipulative capabilities come from the combination of flexible parts (like springs) and connections in their structural design.

3.1.2. Stiffness Enhancement

Flexible robotic surgical systems used in endoluminal procedures need a manipulator that combines dexterity and rigidity. The manipulator has to be flexible so it can reach the damaged area over a lengthy, winding journey. The manipulator needs to be bendable enough to get to the problem location, but then it needs to tighten up once it's there. Flexible surgical robot applications have prompted research into strategies for increasing the stiffness of flexible manipulators to mitigate this tradeoff. Wire tension, friction/interlocking, and phase transition are the primary mechanisms by which these methods alter stiffness. After that, we'll look at a method for increasing stiffness by tensioning wires, which hasn't been covered in any of our prior examinations.

<table>
<thead>
<tr>
<th>Technical challenges</th>
<th>Requirements</th>
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<tr>
<td>precise and reliable intraoperative shape sensing</td>
<td>Safe access to the surgical site and tissue manipulation</td>
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<tr>
<td>tissue interaction force sensing and feedback</td>
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<tr>
<td>Flexible guide tube (or endoscope) with excellent bending capability</td>
<td>Flexibility for access to the surgical site through narrow and tortuous routes via natural orifices</td>
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<td>complete integration of endoscopic functions in a limited overall diameter</td>
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<tr>
<td>the multi-DoF flexible instrument with a thin and compact size</td>
<td>Dexterity, accuracy, and stability for performing surgical interventions in a confined space</td>
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<td>instruments with flexibility but adequate payload/stiffness</td>
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<td>surgical triangulation</td>
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<td>precise control of long and thin flexible instruments</td>
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<td>the ergonomic and intuitive human-robot control interface</td>
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3.1.3. Special Considerations in Manipulator Design

The safety, durability, and accuracy of a flexible manipulator may be improved in some ways by carefully designing its driving mechanisms. An increase in human safety can be achieved by decreasing the passive stiffness of a flexible manipulator. An actuator's torque limitation can switch between three different operating modes: free, active drive and sliding when overloaded. Long-term and stable control in a wire-driven flexible manipulator requires fine-tuning the elongation of the driving wire.

Flexible surgical robots employed a tiny cable with reduced friction. HI-LEX Corp. later marketed this one-of-a-kind cable, and it is now extensively utilized. While designing a flexible manipulator, it is also important to think about the fabrication plan. Subtractive manufacturing and additive manufacturing are the primary production technologies used for prototyping flexible surgical robots. Computerized numerical control machining, laser cutting, and wire electrical discharge machining (EDM) are all examples of common subtractive manufacturing processes. Common methods of 3-D printing used in additive manufacturing are metal printing and laser sintering. Resolution, precision, and mechanical qualities like strength and surface smoothness are all improved in additive manufacturing compared to subtractive manufacturing. Additive manufacturing's strength is in its capacity to produce intricate three-dimensional structures, such as those with numerous working channels or helical tendon courses. In light of this, researchers need to learn the ins and outs of each manufacturing technique and weigh their options based on the manipulator's function, structure, material, and size.

3.2. Modeling and Control

The mechanical architecture of a flexible manipulator whether it has a continuous, discrete, or hybrid backbone, a single backbone, numerous backbones, or only one instrument has a direct impact on how its kinematics may be modeled.

3.2.1. Kinematics and Dynamics Modeling

https://www.malque.pub/ojs/index.php/msj
Kinematics modeling uses terms like location, velocity, and acceleration to describe how things move. Without taking into account the underlying causes, it is just concerned with the mathematical description of motion. Key elements of kinematic models include the following:

- **Position:** The position of an object in space is commonly expressed as three-dimensional Cartesian coordinates with values like \( x \), \( y \), and \( z \).
- **Velocity:** The speed of positional change over time. It gives the direction and speed of an object’s motion. The derivative of the location with respect to time provides the velocity.
- **Acceleration:** The speed at which speed varies throughout time. It displays the rate of change in an object’s velocity. By taking the derivative of velocity to time, acceleration may be calculated.

Kinematic models often use equations such as linear motion equations or equations of motion for rotational motion to describe the relationships between position, velocity, and acceleration.

Dynamics modeling examines the motion-causing forces and how they impact an object’s motion. It includes the investigation of the connections between forces, masses, and accelerations. Newton’s laws of motion, which are essential ideas in classical mechanics, are included into dynamics models. Using Newton’s principles to calculate the motion of an item, including changes in velocity and acceleration, dynamics models often analyze the forces acting on an object.

For comprehending and forecasting the motion of objects in a variety of applications, such as basic mechanical systems to sophisticated mechanical systems, robotics, aeronautical engineering, and more, kinematics and dynamics modeling are essential. These models provide engineers and scientists the tools they need to build and improve systems, simulate motion, and anticipate the behavior of moving objects.

### 3.2.2. Teleoperation and Automatic Control

Steerable-head flexible instruments and flexible devices with several instruments might be challenging for a single operator to manage manually. This supports the automation of any equipment used in endoluminal procedures, no matter how simple they may seem. In the field of robotic surgery, M-S robots are created with many goals in mind. Communication with the surgeon to ensure patient safety and compliance with regulations. Both rigid and flexible instrument tele manipulation share these goals. Robotic instruments are essential for the widespread clinical adoption of flexible instruments and endoluminal applications since manual techniques need in-depth education and are often limited in their use.

- **M–S mapping strategy:** The strategy’s end objective is to shorten the learning curve and increase safety by allowing the surgeon to make intuitive movements. Interfaces that aren’t well thought out diminish the robot’s usability and the surgeon’s comfort.

![Figure 1 Control loop for M-S](https://www.malque.pub/ojs/index.php/msj)
The latter calls for including an inverse kinematics calculation into the mapping procedure (see Figure 1). Master interface motion must stay away from the singularity and the boundary of the interface if manipulability and motion scaling is to be achieved. Given these constraints, it will be necessary to create specialized medical robot interfaces rather than employing off-the-shelf solutions. The surgeon's whole attention should be on the operation at hand, not on the mechanics of which buttons to press, pedals to engage, or arm motions to carry out.

3.2.3. Team SoloMid (TSM) Hysteresis Compensation

TSM is a typical actuation mechanism used in flexible surgical robots to achieve steer ability. This mechanism's benefits include adaptability, high transmission efficiency, and a small manipulator footprint. As a result, the performance of flexible surgical robots is hindered by the delay and decrease in control precision introduced by standard kinematic control methods. Hysteresis is a common problem with endoluminal-applicable flexible surgical robots due to the lengthy and winding tendon design of the manipulators, which causes a lot of friction force and wire distortion. As a result, many people have put a lot of time and energy into developing both offline and online methods to counteract the impact of hysteresis.

3.3. Shape and Force Sensing

3.3.1. Shape Sensing

The deformability, compliance, redundancy, and unavoidable interaction with surrounding tissue of surgical flexible manipulators make it challenging to accurately estimate the shape and posture of the manipulator using kinematics and mechanics-based models. Uncertain model parameters and the influence of external loads, which lead to substantial changes in form and kinematics, make it challenging to use this model-based method. Due to inaccurate position input, the flexible manipulator cannot be safely guided to the surgical site. New sensor-based techniques are into one of three categories: those based on optical fiber sensors, electromagnetic sensors, or intraoperative images. These methods are used as the flexible tool used in endoluminal surgery not only for accurate control but also for navigation and contact-force measurement. This section gives a high-level overview of each technology, including its underlying principles and the most recent advancements in the field.

3.3.2. Force Sensing

Some aspects of endoluminal surgery are unique to this kind of surgery, making contact sensing between the device and organ particularly crucial: The esophagus, colon, blood vessels, and ureter are all relatively fragile organs that the endoscope will inevitably come into contact with as it makes its way to the surgical site through long, narrow, and curved pathways. Surgeons doing manual endoluminal operations have tactile sensations at the site of tissue contact. The patient's well-being is intimately linked to the haptic data's application to the evaluation of contact and tissue damage. Therefore, surgeons using robotic systems must understand the force exerted by each tool on the tissue. Although haptic or tactile feedback has not been used in existing flexible robotic surgical systems, various researchers have measured the interaction forces involved.

4. Flexible Robotic Systems for Endoluminal Applications

Pioneering work on flexible surgical robots has resulted in the development of an M-S-type active endoscope, which has been in use since the late 1980s. Each endoluminal application (gastrointestinal endoscopic surgery, ureteroscopic surgery, bronchoscopy, and endovascular surgery) is analyzed in detail, including their clinical achievements using the corresponding flexible robot system. Several recent medical studies have reviewed the use of robots in endoluminal and transluminal endoscopic operations.

![Figure 2](https://www.malque.pub/ojs/index.php/msj)
4.1. Gastrointestinal Endoscopic

Surgery one of the most popular uses of surgical robots nowadays is in the area of gastroenterological endoscopy. So, the traditional gastrointestinal endoscope’s difficulties in manipulation and dexterity instrument movements may be overcome with robotic help, allowing for more effective diagnostics and treatments. When it comes to gastrointestinal endoscopy, robots may be of use in two distinct ways: during insertion and operation. In particular, this article examines the role that robotic devices may play in facilitating endoscopic surgery. Two robotic devices with articulated joints are often part of these flexible systems and may be mounted to the outside of a flexible endoscope or inserted inside the endoscopic channels. All of the tools (including the endoscope) may be used with a single hand or remotely controlled by a commercial or bespoke master device. Many similar systems are practical and beneficial in preclinical or clinical testing, and one is already available on the market. Originally, they were conceived as a “mechanical system” in which two operators would use a handle or knob attached to the endoscope and surgical equipment to perform the procedures. To further increase intuitiveness, ergonomics, and accuracy, and decrease the number of operators needed, technology eventually developed into the “robotic M-S system,” which enables the remote operation of the endoscope or surgical tools.

4.1.1. Mechanical System

a) COBRA

USGI Medical’s (San Clemente, California) COBRA resect scope has a shape-locking scope with three extra arms. By applying strain to the wires connecting the connections in a serial configuration, the scope can lock its form into place. The scope may be locked into a hard configuration to offer a secure platform for surgery, and it can be flexible during insertion. Using an endoscopic triangulation, the camera and two surgical tools may be moved independently of one another, allowing for traction and counter traction to be performed while retaining clear optics. Laboratory reports indicate that complex operations, such as suturing and tying sutures, done using COBRA may be challenging because of the limits of imprecise cable-driven controls and the inability to change tools. There have been no more reports of either preclinical or clinical findings.

b) R-Scope

The main flexure may be fixed in place by increasing the tension on the actuation wire, and the secondary flexure can be placed anywhere the user sees fit. The scope and the two instruments are controlled by a single knob on the control body. Animal and human trials were conducted first to ensure the device was effective for gastric ESD. However, due mostly to the operator’s incompetence, the outcomes were subpar, with perforations occurring in about 20% of both instances. Clinical research using gastric ESD for superficial gastric neoplasm revealed similar en-bloc resection, complication, and local recurrence outcomes to those of conventional ESD, with a much shorter operation duration. Complex controls that are
difficult for a single operator to master, as well as subpar instrument performance in retroflexion, are two of the system's major drawbacks.

c) Direct-drive endoscopic system

Boston Scientific's (Marlborough, MA, USA) Direct-drive endoscopic system (DDES) is a manually operated, multifunctional platform designed for endoluminal and NOTES procedures. Each tool has an ergonomically designed handle that powers a long flexible shaft that terminates in an individual end effector. The guide sheath adds two degrees of freedom to the seven DoFs at the instrument tip, which are transmitted from the handle. Endoscopic mucosal excision is just some of the complicated non-surgical activities that the DDES is capable of in ex vivo and in vivo animal testing.

d) Endo SAMURAI

Olympus's Endo SAMURAI is a versatile endoscopic device for performing intraluminal and transluminal treatments. A bendable endoscope, two articulated working arms equipped with surgical end effectors, and a control unit makes up the system. The flexible endoscope's directional and locking capabilities allow it to serve as a system stabilizer. In difficult endoscopic procedures, including endoscopic full-thickness resection, the technology proves more accurate and requires less time than a traditional endoscope. A small bowel anastomosis might also be completed promptly and to an acceptable standard. Cutting, suturing, and tying knots were accomplished with accuracy and effectiveness on par with laparoscopic instrumentation, but with a greater time investment.

4.1.2. Robotic M–S System

a) ViaCath

EndoVia Medical's ViaCath system is the first tele operated robot designed specifically for endoluminal procedures. In comparison to an endoscope, the two robotic devices that extend from their distal ends are more sophisticated, allowing for the bimanual manipulation of tissues. The endoscope's field of view may be manipulated in seven degrees of freedom (DoFs) thanks to the instrument's positioning arm. Multiple animal experiments, both in vitro and on living subjects, confirmed the system's viability. Mucosal excision and fundamental suturing in the digestive tract were achieved with the help of the available tools and system. To address issues including awkward endoscope insertion into the stomach and weak instrument manipulation force, a newer generation of equipment was developed.

b) Endo MASTER

The Endo Master was developed at Nanyang Technological University as a robot-assisted surgical device for use in NOTES procedures. Endoscopic removal of polyps and cancers in the digestive tract was among the first uses. The Endo Master is a flexible endoscope with two robotic arms built onto its tip to increase its agility. This allows for precise tissue manipulation and dissection. Complete excision of stomach neoplasms was achieved in a small-scale, human preclinical experiment, and no patients had any adverse effects. A colonic ESD was performed without perforation using the newest version of the Endo Master EASE System in a pig model. The first patients enrolled in a clinical trial to treat colorectal lesions in May 2020, and the study ran until December 2021. Notably, there have been cadaver studies for transoral uses.

c) FLEX robotic system

Intrapericardial uses inspired the initial design of the FLEX² robotic system by Medrobotics Corporation. Transoral and transanalendoluminal surgeries are now possible with the upgraded device. The system consists of a robot-assisted flexible endoscope (RAFE), a set of flexible instruments that are compatible with the RAFE, and a control station. The FLEX scope has two connections, as opposed to one in a standard flexible scope: a distal one and a leading one. The articulating instrument has four degrees of freedom (DoF), with the user controlling two directional bendings through a grip attached to the flexible shaft. Transoral surgical operations involving the pharynx and larynx have demonstrated promise in the system's first clinical trial. In 2014, it was given the European CE mark, and in 2015, it was given FDA authorization for use in transoral surgeries. In 2017, the FDA gave the technology the go-light for use in colorectal endoscopies. The viability of some colorectal operations, including transanal TME (taTME) and transvaginal rectopexy, was studied using cadaveric follow-up experiments.

d) Robot-assisted flexible endoscope

Kyushu University (Fukuoka, Japan) has created a platform called RAFE that is optimized for ESD. The basic idea behind the platform is to adapt existing standard endoscopes for usage with a flexible surgical robot. The endoscope's extended motor unit controls all degrees of freedom. There are two bending degrees of freedom (DoFs) in the platform's articulating instruments. Both are placed via the endoscope, one through a regular channel and the other through a specialized tube at the end.
4.2. **Urteroscopic Surgery**

The flexible ureteroscope is being used in conjunction with robotic assistance primarily for the treatment of kidney stones. The weariness of the surgeon due to a non-ergonomic position is a significant drawback of traditional flexible ureteroscopy in renal stone removal, potentially decreasing surgical efficiency and safety and increasing the risk of damage to the surgeon. The robot systems use robotized ureteroscopy manipulation to reduce radiation exposure and improve surgeon comfort during urological procedures. The standard setup for such a system includes a slave robot arm on which is attached a commercial flexible ureteroscope, and a control panel from which the endoscope and other equipment may be remotely manipulated.

4.2.1. **Roboflex Avicenna**

ELMED Medical Systems has created the first robot-assisted flexible ureteroscope device intended for kidney stone therapy called Roboflex Avicenna1. A bendable ureterorenoscopy manipulator and a surgeon's station with a built-in touch screen and two joystick interfaces make up this device. The robotic arm's hand component is compatible with the most available ureterorenoscopy on the market today. The device has pneumatically actuated 2-foot pedals for activating fluorooscopy and laser shooting. Motorized insertion and withdrawal of the laser fiber and variable rates of irrigation fluid infusion are also available. The first clinical trial confirmed that the device is capable of performing all current protocols and procedures associated with flexible ureteroscopes, including laser dusting and the removal of bigger pieces, with a good effect on ergonomics and a reduction in radiation exposure to the surgeon. Additional clinical investigations confirmed the system's safety and effectiveness and compared well to the standard approach in terms of stone-free rate, treatment time, and intraoperative complications. In 2013, the system was awarded the CE mark, and it is now awaiting FDA clearance.

4.3. **Bronchoscopic**

4.3.1. **Monarch**

Robotic bronchoscope system with built-in electromagnetic navigation (EMN) guidance, created by Auris Health. It also has safety features like monitoring driving tension and automatically releasing tension when the scope is retracted. The simulated peripheral pulmonary lesions were successfully biopsied and the peripheral airways were more accessible in cadaver tests. Initial clinical studies showed the platform to be technically viable for diagnostic bronchoscopy. Recent research has shown that robotic bronchoscopy is a safe and effective treatment option for individuals with peripheral pulmonary lesions. In 96% of patients, lesion localization was confirmed, and the risk of adverse events was similar to that seen with traditional bronchoscopy. The Food and Drug Administration (FDA) has given its blessing to the platform for diagnostic and therapeutic bronchoscopic operations in 2018.

4.3.2. **ION Robotic Endoluminal System**

Robotic catheters like Intuitive's (Sunnyvale, CA, USA) ION robotic endoluminal systems use shape-sensing technology to provide the user input on the catheter's location and form. The technology consists of a robotic articulating catheter that is flexible in any direction by up to 180 degrees and includes a shape-sensing fiber embedded along its length. In addition to the catheter, there is a program that reconstructs the airways virtually in 3D and displays a route to the desired location automatically. The next step is to use the shape-sensing fiber's position information to register rather than relying on EM position sensing. The technology proved its efficacy in cadaver research, where it was used to successfully puncture tiny nodules on the lung's periphery. The most recent clinical investigation was 92%, and there was hardly any risk of complications. In 2019, the technology was given FDA permission for use in peripheral lung biopsy using a minimally invasive approach.

4.4. **Endovascular Surgery**

Endovascular procedures may now be performed with the same ease using flexible surgical robot technology. Endovascular surgery has gone a long way in terms of technology, but there are still significant barriers to effective surgical results, such as the dependence on lesion sites, vascular operator skill, and a lack of accurate placement of intravascular devices. To make it easier to access challenging lesions, robot systems have been created to give accurate guide wire and catheter control. The resultant efficacy has the potential to shorten fluorooscopy times, protecting the surgeon and the patient from unnecessary radiation exposure.

4.4.1. **Sensei X**

Hansen Medical’s Sensei (Mountain View, CA, USA) is a control and positioning system for catheters in the circulatory system that aims to make them easier to use. The M-S electromechanical system allows the clinician to manipulate the
guiding catheter and sheath. Sensei X, the latest iteration of the technology, has an artisan stretched catheter that allows for 270 degrees of the catheter and a remote-controlled tip that can be manipulated in three dimensions. The vibrations are sent to the user via the controller, creating a haptic effect. The feasibility and efficacy of using Sensei X to treat AF were assessed. Compared to manual ablation, the results showed that employing the robotic method resulted in similar rates of problems and recurrence, although much less radiation exposure was experienced. The system received both CE and FDA markings in 2007.

4.4.2. Magellan

Redesigned for peripheral endovascular intervention, the Magellan1 robot was developed by Hansen Medical. The system’s core features include a robot arm and an operator console for remote manipulation of steerable catheters and standard guide wires. The radiation source is placed in a different room from the control room. There was less catheter-tissue contact and less vascular stress from catheter contact with the vessel wall, according to phantom research. Fenestrated endovascular repair (FEVAR) was successfully performed in clinical trials, demonstrating the system’s viability. These results also suggested that it would be possible to reduce the operator’s exposure to radiation and streamline difficult endovascular procedures. No access site difficulties occurred during tibiofemoral artery navigation, and the procedure was straightforward for even inexperienced operators. The technique showed promise in thoracic endovascular aortic repair, with much-reduced embolization, possibly due to the robotic catheter’s enhanced agility and control, which lessens the likelihood of accidental contact with the artery wall. In 2011, the system was granted the CE mark, and in 2012, it was granted FDA 510(k) approval for use in guiding guide wires and robotic catheters via peripheral vessels.

4.4.3. R-One

The robot has both a control unit and a robotic unit, both of which are shielded from radio waves. Within a radiation-safe zone, surgeons may use the control unit to operate a catheter and guide wire from a distance. The robotic system allows for the automated use of the best guide wires and catheters on the market. There have been no published publications detailing the outcomes of clinical trials. By 2021, RoboCath expects to have performed its first robotic coronary angioplasties in many European nations, as well as in Africa and China. In addition, a European clinical investigation utilizing robot-assisted percutaneous coronary intervention (PCI) using RoboCath will have finished enrolling patients in 2021. In 2019, RoboCath received the CE certification, allowing it to be used in cardiac interventions.

5. Conclusion

Several adaptable robotic surgical systems have been developed to do endoluminal surgery alongside the commercial success of the da Vinci laparoscopic robotic surgical system. But there are technological challenges that need to be overcome when it comes to maneuvering deftly in the lumen’s curved and restricted environment. This article reviewed state-of-the-art research activities that are being done to solve these technical problems. Both robotic surgery and endoscopy stand to benefit from this new technology if the findings of this study are implemented in flexible surgical robots. Through endoluminal, transluminal, and extraluminal techniques, surgeons will have access to more broadly applicable robotic treatments that need little to no incision. Furthermore, with the use of delicate surgical movements and navigational support, endoscopists will be able to undertake more sophisticated endoscopic diagnostics and endoscopic tumor resections. Regardless of the surgeon’s endoscopy expertise or the degree of complexity of the procedure, the modern endoscopic surgical robot will provide consistent results. New surgical tools, such as laser, cryogenic, and electrical devices, will be developed with the help of these high-tech robots. When compared to traditional rigid-type laparoscopic robotic surgical systems, flexible surgical robots will allow the advantages of robotics to be applied to a wider variety of surgical procedures.

Ethical considerations

Not applicable.

Declaration of interest

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